LEVEL III

NRL Memorandum Report 4328

AD A093 265

Sonar Transducer Reliability Improvement Program FY 80

Fourth Quarter Progress

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October 1, 1980

NAVAL RESEARCH LABORATORY
Washington, D.C.

80 12 05 093

UNCLASSIFIED (14) NRL-MR-4328

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 4328	2. GOVT ACCESSION NO. AD-A092651	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) Sonar Transducer Reliability Improvement Program (STRIP) FY80. ~~Fourth Quarter Progress Report.~~ A097193		5. TYPE OF REPORT & PERIOD COVERED Interim report on a continuing problem
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) R. W. Timme	(9) Quarterly progress rept. no. 4	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Underwater Sound Reference Detachment Naval Research Laboratory P.O. Box 8337, Orlando, FL 32856		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Work Unit 0584-0 Program Element 645034
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command (Code 63X5-1) Washington, DC		12. REPORT DATE (11) 1 Oct ~~ober 1980~~ 80
		13. NUMBER OF PAGES 66
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 67		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

The Sonar Transducer Reliability Improvement Program (STRIP) is sponsored by NAVSEA 63X5

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Transducers	Cables	Noise
Corona	Connectors	Material Evaluation
Transducer Fluids	Noise & Vibration	Water Permeation
Encapsulation	Pressure Release	Environmental Tests

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Progress accomplished during the fourth quarter of FY80 in the Sonar Transducer Reliability Improvement Program (STRIP) is reported. Each of the 6 major task areas is discussed in detail. Goals completed this quarter include:

- Accelerated life testing (ALT) of the TR-316 transducers has shown air bubbles of substantial size may form during operation. At present, the air bubbles have not affected the acoustic performance sufficiently to be out of specification.

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S/N 0102-LF-014-6601

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BLOCK 20 - ABSTRACT - continued

- Recent measurements have shown that safe operating voltage levels in transducers decrease as the operational frequency increases. Strong doubt is also cast on final checkout procedures in which a dc or low-frequency voltage, rather than high voltages at operating frequencies, is applied in a pass/fail test.

- It was found that the atmosphere in even well sealed transducers, such as the TR-208A, contains sufficient moisture to cause significant changes in the impedance of the transducer.

- A report on the Composite Unit Accelerated Life Test (CUALT) procedures for the AN/SQS-56 transducer elements has been completed.

- During FY80, 20 reports have been issued.

CONTENTS

Sonar Transducer Reliability Improvement Program
NRL Problem 0584
FY80 Fourth Quarter Progress Report

1. INTRODUCTION

1.1. PROGRAM OVERVIEW

The general objective of this program is to perform relevant engineering development which addresses the operational requirements for fleet transducers for active sonar, passive sonar, surveillance, counter-measures and deception devices, navigation, and acoustic communications. The approach is to develop, test, and evaluate improved transducer design, materials, components, and piece-parts that will meet specified requirements in the operational environment during the entire useful life of the transducer. Standards will be prepared to ensure that results obtained during preliminary testing will be obtained consistently in production. This program should result in improved performance and reliability and reduced costs through better utilization and a more comprehensive characterization of materials and design data. The program goals are as follows:

- Reduction in transducer replacement costs

  Goal - less than 9% of population replaced each year with no automatic replacements at overhaul.
  Threshold - less than 18% of population replaced each year.

- Improvement in transducer reliability

  Goal - less than 1% of population failures each year.
  Threshold - less than 3% of population failures each year.

- Improvement in transducer receiving sensitivity

  Goal - less than ±1 dB variation from the specified value over operational frequency band.
  Threshold - less than ±2 dB variation from the specified value over operational frequency band.

The Sonar Transducer Reliability Improvement Program (STRIP) is a part of Program Element 64503N. Major task areas with specific objectives to achieve the program goals have been described in the Program Plan and include:

- Task Area A - Encapsulation Methods
- Task Area B - High Voltage Engineering

- Task Area C - Cables and Connectors
- Task Area D - Transducer Material Standards
- Task Area E - Environmental Test Methods
- Task Area F - Transducer Tests and Evaluation

The FY80 Program Plan for STRIP has been funded at the $495K level. The specific tasks and their Principal Investigators for FY80 are listed below:

TASK		PRINCIPAL INVESTIGATOR	
A-1	Fluids and Specifications	NRL	C.M. Thompson
A-2	Encapsulants and Specifications	NRL	C.M. Thompson
B-1	Corona Abatement	NRL	L.P. Browder
C-1	Handbook for Harness Design	GD/EB	R.F. Haworth
C-2	Standard for O-Ring Installation	APL/University of Washington	C.J. Sandwith
C-3	Cable and Connectors	TRI	D.E. Glowe
D-1	Alternative Materials - Plastics	NWSC	K. Niemiller
D-2	Pressure Release Materials	NUSC	C.L. LeBlanc
E-1	CUALT	NOSC	J. Wong
E-2	ALT Verification	NWSC	D.J. Steele
F-1	Failure Modes Due to Water	TRI	D. Barrett
F-2	Shock-Hardened Pressure Release	Westinghouse	C.R. Wilson
F-3	Reliability & Life Prediction Specification	TRI	R.L. Smith
F-4	Engineering Documentation	NRL	R.W. Timme

1.2. SUMMARY OF PROGRESS

During the fourth quarter of FY80, efforts in the various tasks of STRIP have resulted in progress toward the program goals as summarized below:

- Accelerated Life Testing (ALT) of the TR-316 transducers has shown air bubbles of substantial size (3-5 cm) may form during operation. At present, the air bubbles have not affected the acoustic performance sufficiently to be out of specification. See Section 9.3.1.

- Recent measurements have shown that safe operating voltage levels in transducers decrease as the operational frequency increases. Strong doubt is also cast on final checkout procedures in which a dc or low-frequency voltage, rather than high voltages at operating frequencies, is applied in a pass/fail test. See Section 4.3.3.

- It has been found that the atmosphere in even well sealed transducers, such as the TR-208A, contains sufficient moisture to cause significant changes in the impedance of the transducer. See Section 11.3.

- A report on the Composite Unit Accelerated Life Test (CUALT) procedures for the AN/SQS-56 transducer elements has been completed. See Section 9.3.3

- During FY80, the following reports have been issued:

  - C.I. Bohman, "Results of Radiated Self-Noise Measurements of TR-215 Transducers," NOSC Tech Note 647

  - J.S. Thornton, "Accelerated Life Testing of Adhesive Bonds," TRI Tech Report 7973 (oral presentation at STRIP Annual Review)

  - E.W. Thomas, "Evaluation of UQN-1 (TR-297) Transducer Modifications," NRL Memo Report 4140

  - R.L. Smith, "Development of a Low-Noise Pressure-Release Sleeve-Spring for the TR-155 Transducer," TRI Tech Report 7853F

  - D.L. Carson, "Composite Unit Accelerated Life Testing of Sonar Transducers," NOSC Tech Report 516

  - R.L. Smith, "Reliability and Service Life Concepts," Presentation at NOSC, Oct 1979

  - D. Glowe, "Investigation of Cables and Connectors," Marine Technology Society Conference, Mar 1980

  - A.M. Young & R.L. Smith, "Development of an Alternative Pressure-Release Mechanism for the TR-155 Transducer," NRL Report 8396

- L.E. Horsley, "The Acoustic Decoupling Properties of Cork-Rubber Composite Materials as a Function of Transducer Fill-Fluid Absorption," M.S. Thesis at Florida Institute of Technology

- C.M. Thompson, "Permeation into Containers Filled with Non-Ideal Oil," to be published in Journal of Applied Polymer Science

- L.P. Browder, "High-Voltage Lifetime Function of PZT Ceramic/Gas Insulator Interface in Underwater Sound Transducers," NRL Memo Report 4321

- J.S. Thornton, "Qualification and Composite Unit Accelerated Life Test Recommendations for AN/SQS-56 Sonar Transducer Elements," TRI Tech Report 7968-5.1

- J.S. Thornton, "Accelerated Aging of DT-168 Hydrophones to Simulate USS STONEWALL JACKSON Service," TRI Tech Report 7973-4

- C.M. Thompson and L.E. Horsley, "Aging of Cork-Rubber Decoupling Materials," NRL Report 8458

- C.M. Thompson, "Transducer Fill-Fluids," <u>Handbook of Sonar Transducer Passive Materials</u> (edited by R.N. Capps), Chapter 4, pp 269-323

- R.W. Timme, "Sonar Transducer Reliability Improvement Program FY79 Fourth Quarter Progress," NRL Memo Report 4058

- R.W. Timme, "Sonar Transducer Reliability Improvement Program FY80 First Quarter Progress," NRL Memo Report 4166

- R.W. Timme, " Sonar Transducer Reliability Improvement Program FY80 Second Quarter Progress," NRL Memo Report 4196

- R.W. Timme, "Sonar Transducer Reliability Improvement Program FY80 Third Quarter Progress, NRL Memo Report 4257

- R.W. Timme, "STRIP Program Plan for FY81"

1.3. PLANS

The Program Plan for FY81 STRIP has been approved by NAVSEA at the $1015K level. This funding level will be committed among the following tasks:

	TASKS	PRINCIPAL INVESTIGATORS	
A	Encapsulation Methods	NRL-USRD	C.M. Thompson
B	High Voltage Engineering	NRL-USRD	L.P. Browder
C-1	Cable Configuration and Materials	Contractor	
C-2	Cable Specifications	Contractor	
C-3	Handbook for Harness Design	GD/EB	R.F. Haworth
C-4	Standard for O-Ring Installation	APL/University of Washington	C.J. Sandwith
D-1	Pressure Release Materials	NUSC	C.L. LeBlanc
D-2	Alternative Materials - Plastics	NWSC	K. Niemiller
D-3	Specification of Elastomers	NRL-USRD	C.M. Thompson
D-4	Transducer Ceramics	NRL-USRD	A.C. Tims
E-1	CUALT	NOSC	J. Wong
E-2	ALT Verification	NWSC	D.J. Steele
F-1	Failure Modes Due to Water	TRI	P.E. Cassidy
F-2	Ceramic Stack Joints	NOSC	C.I. Bohman
F-3	Metal Matrix Composites	Honeywell	O.L. Akervold
F-4	Reliability & Life Prediction Specification	TRI	R.L. Smith
F-5	TR-122 FMA & Improvements	NRL-USRD	R.W. Timme
F-6	Improved Hydrophone Analysis	NWSC	D.J. Steele
F-7	Engineering Documentation	NRL-USRD	R.W. Timme

Productivity for FY81 is expected to include the following:

- Interim report on properties of various fill-fluids
- Interim report on encapsulation materials
- Development of a nonproprietary moca-free encapsulant

- Final report on ceramic-voltage lifetime function
- Interim report on corona reducing coatings
- Preliminary specification for corona
- Final report on connector backshell leakage
- Handbook for cable harness design
- Standard for O-ring installation
- Report on cable shielding and EMI
- Interim report on cable specifications
- Final report on pressure release materials
- Final report on water permeation of elastomers
- Preliminary specification for neoprene
- Final report on accelerated life testing for BQS-8/10/14/20
- Interim report on accelerated life testing for SQS-56
- Interim report on failure modes of transducers due to water
- Final report on reliable transducer ceramic stacks
- Final report on metal matrix composites in transducers
- Draft of a reliability and life prediction specification
- Final report on TR-122 improvements
- Interim report on DT-276 improvement alternatives
- Four quarterly reports and annual review

1.4. REPORT ORGANIZATION

The remaining sections of this quarterly report will discuss the objectives, progress, and plans for the specific tasks included in the STRIP.

2. TASK A-1 - TRANSDUCER FLUIDS AND SPECIFICATIONS

C.M. Thompson - NRL-USRD

2.1 BACKGROUND

A material to be used for filling a sonar transducer must meet a wide variety of specifications. The requirements imposed by the electrical nature of the device include high resistivity, high dielectric constant, as well as resistance to corona and arc discharges. The water environment of the transducer necessitates low water solubility and other attractive solution properties. In addition, the fluid must maintain its electrical and other properties in the presence of any water which permeates the covering. The acoustic requirements are a close acoustic impedance match with seawater and resistance to cavitation at high-drive levels. Other obvious properties include compatibility with other components, stability to degradation, and suitable surface tension and viscosity.

With such a wide variety of requirements, it is not surprising that compromises have to be made. The most commonly used fluid for many years has been castor oil. This use is in spite of its high viscosity. Each of the fluids proposed, so far, as a replacement has serious drawbacks. Silicone oils tend to creep onto and wet all of the surfaces of the transducer. This greatly complicates bonding the components together. Polyalkylene glycol (PAG) has the disadvantages of a high water solubility and low electrical resistivity. The various hydrocarbon liquids have too low an acoustic impedance and are frequently incompatible with the various plastics and rubbers in the transducer. Further research is necessary to find and qualify fill-fluids which represent the best match to all the requirements imposed upon it.

2.2. OBJECTIVES

The objectives of this task are:

- To find plausible new transducer fill-fluids which combine the best properties. Candidates include: hydrophobic-polyethers, sterically protected esters, chlorine - or fluorine - containing hydrocarbons, and possible aromatic hydrocarbons.

- To apply the criteria developed during the PAG and castor oil testing to the most promising candidate fluids.

2.3. PROGRESS

2.3.1 During this quarter a compilation has been completed of the values of the relevant properties of 25 transducer and towed-array fill-fluids.

These fluids are listed below:

Castor Oil, Baker DB Grade	Robuoy, Robeco Chemical Co.
Lubricin Castor Oil	Transformer Oil, Texaco No. 55
Tricresyl Phosphate (TCP)	Motor Oil, Cam 2, 20W-50 Viscosity
Polyalkylene Glycol (PAG) Union Carbide LB135Y23	Fluorinert, FC 75, 3M Company
Dow Chemical Co. P4000	Fluorolube, FS-5 Hooker Chemical Co.
Polyglycol	SF1147 Methyl alkyl silicone General Electric Co.
Dow Chemical Co. 112-2 Polyglycol	Dow Corning FS-1265
Dow Corning 200.5 Silicone	Isopar L (Exxon Co.)
Dow Corning 200.20 Silicone	Isopar M (Exxon Co.)
Dow Corning 200.10 Silicone	Norpar 12
Dow Corning 200.100	Shell Sol 71 (Shell Chemical Co.)
Dow Corning 220 Silicone	Polyalphaolefin (PAO) (Uniroyal PAO-20E)
Dow Corning DC 510/100	Robane, Robeco Chemical Co.

The data for this compilation was taken from published sources and manufacturers' literature, but principally from unpublished results of work performed at USRD. This compilation, along with a brief discussion of the criteria for selecting transducer fluids, will be published as a chapter in "Handbook of Sonar Transducer Passive Materials" edited by R.N. Capps. The handbook will be published as an NRL Memorandum Report. Requests for copies may be addressed to this author or the handbook editor. Comments about the contents are welcomed.

2.4. PLANS

- Publish a report of transducer fluid properties with a more detailed discussion of fluid selection criteria (1st Qtr, FY81).

- Re-start testing on modified PTMG, a candidate transducer fill-fluid (3rd Qtr, FY81).

- Publish a report on water permeation in sonar transducers and the effect this has on operation and lifetime (cooperative between Tasks A-1 and F-1).

3. TASK A-2 - ENCAPSULANTS AND SPECIFICATIONS

C.M. Thompson - NRL-USRD

3.1. BACKGROUND

Transducer encapsulants have long presented a source of transducer failure. The necessity that the encapsulants be resistant to water, have a sufficiently long pot-life for de-gassing, bond well to the other components, and have high strength has proved to present a very difficult problem. Many other requirements also apply in special cases. The best choice for a polyurethane encapsulant to date has been a toluene diisocyanate (TDI)-polytetramethylene glycol (PTMG) prepolymer which is chain extended with 4,4'-methylene-bisorthochloroaniline (MOCA). This encapsulant has a long pot-life, good strength, and good water resistance. However, there is serious concern for the health hazards of both the MOCA and the TDI residue in the prepolymers.

3.2. OBJECTIVES

The objectives are to define the relative importance of the properties of transducer encapsulants and to produce a non-hazardous replacement for currently used materials.

3.3. PROGRESS

The variations of diisocyanate, soft block materials (e.g., PTMG) and chain extender can produce a bewildering array of different polyurethane encapsulants. The variety is somewhat simplified by the transducer community's necessity for de-gassing, with the attendant long pot-life. The only way to achieve this in the past - and maintain high strength - has been to use a chain extender which is deactivated until heat is applied. The best example of this is the MOCA molecule, where the chlorine atom shields the adjacent active amine group from the active sites on the prepolymer. Only when heat is applied is there sufficient motion of the atoms to allow the amine group to approach the prepolymer and produce cross-links.

Because of the desirability of the MOCA-type reaction, initial efforts have been directed at a similar chain extender; 4,4'-methylenebisortho-methylaniline (MOMA) should exhibit much the same properties as MOCA but possibly without the carcinogenicity. MOMA is not a commercially available material, so it is necessary to synthesize it in the laboratory; this effort is now underway. Another likely candidate for a chain extender is 2,5-dimethyl 2,5-hexanediamine (DMHD). This compound is commercially available and has been tested elsewhere as a chain extender in hard epoxy resins.

Other work has been done with several of the diamino-naphthyl- and diamino-phenyl-compounds as chain extenders. None of these compounds provide sufficient pot-life. Additionally, they are very hazardous materials.

3.4. PLANS

- Prepare or acquire a sample of MOMA and test its usefulness as a chain extender.
- Acquire and test DMHD as a polyurethane chain extender.
- Continue study of correlations among pertinent properties of encapsulants.

4. TASK B-1 - CORONA ABATEMENT

L.P. Browder - NRL-USRD

4.1. BACKGROUND

A significant percentage of transducer failures is due to voltage breakdown of insulating materials developing from corona erosion mechanisms. It is not practical to test the end item (transducer) to quantify the effects of corona erosion on transducer reliability and lifetime. Corona must be studied as a failure mechanism at the component or piece-part level to quantify the protection requirements and establish reliability factors. Transducer reliability may then be achieved by control of design parameters and construction processes.

4.2. OBJECTIVES

The objectives of this task for FY80 are:

- A complete investigation of the lifetime function of PZT ceramic exposed to various levels of corona discharges in different gases and gas impurity mixtures.
- A formulation of the elementary transducer reliability function based on electrical breakdown considerations.

4.3. PROGRESS

4.3.1. NRL Memorandum Report 4321 entitled "High-Voltage Lifetime Function of the PZT Ceramic/Gas Insulator Interface in Underwater Sound Transducers" is complete and being distributed. The report summarizes test results of time-to-breakdown versus 60 Hz drive voltage for a PZT ceramic surface in the presence of normally occurring electrical discharges with various insulator gases. This area of the transducer is the electrical weak point of the insulation system. The lifetime function curves are related to the mathematical expression

$$t = c[(V/V_a) - 1]^{-n} \qquad (1)$$

where t is time-to-breakdown, V is the operating voltage, V_a is a voltage level asymptote where t is large and the exponent n is a constant determined from the data. The value for the constant c for each insulator gas is evaluated with the formula

$$c = [(V_1/V_a) - 1]^n \qquad (2)$$

in which V_1 is the voltage level of Eq. (1) where t = 1 hr.

The report concludes by answering several important general questions about the electrical lifetime of sonar transducers. Most of these concern the effects of design parameters on electrical lifetime, but some are related to general electrical specification requirements.

4.3.2. A report is being prepared that combines the empirical mathematical functions from these corona abatement studies into a formulation of the elementary transducer reliability function based on electrical breakdown considerations. The report assumes that electrical breakdown will occur on the PZT/gas interface and that a specific electrical breakdown voltage can be assigned for standardized conditions of operation. Normalized multiplier factors are determined for each of the variable conditions of

- Random failures
- Ceramic thickness
- Type insulator gas
- Air contamination of the gas
- Gas pressure
- Water vapor contamination of the gas
- Operating temperature
- Transducer operating frequency (discussed in next section)

The combined product of the standard breakdown voltage and the normalized multiplier factors yields a modified breakdown voltage factor. Other formulas provide for using this voltage to compute either breakdown voltage at a given voltage exposure time or time to breakdown at a given voltage level. In either case, the time parameter (T) refers to the mean time before failure for voltage breakdown. In relating T (hours) to the transducer age at failure, a duty ratio factor of voltage exposure time to real time is assumed, for convenience it is made 1 hr/yr. The general reliability formulas for random failures at constant failure rate are used to compute the reliability factors.

The combination of formulas and factors in the report are adaptable to convenient mathematical modeling of electrical reliability in sonar transducers. The method used by the analysis is both specific and general. Specific estimates of electrical reliability are obtained using the standard parameter values. General improvement of the estimates is achieved from life test results or operating experience. The method is also expandable to include other factors that may be discovered that affect sonar transducer electrical reliability.

4.3.3. Tests were conducted to evaluate the high-voltage breakdown of the PZT ceramic/gas interface at frequencies up to 20 kHz. The voltage source used for the tests was a 10 kW power amplifier with a special step-up output transformer manufactured by Instruments, Inc. This amplifier was able to provide voltage drive of 4.5 kV or a voltage stress of 7.08 kV/cm (18 V/mil) to a 0.635-cm thickness PZT ceramic specimen. The electrical discharge phenomena to be observed included flashover, high-level corona, and parasitic current pulses. The parasitic current pulses [1] are current spikes occurring on the drive voltage peaks that increase in amplitude prior to breakdown. These effects were detected using a current transformer on the drive line to the specimen and a low-noise amplifier with a tunable frequency notch filter to modify the received signal. The fundamental frequency current component was rejected by the filter and the current discharges were observed on a high-gain oscilloscope. These measurements were made with the specimen enclosed in a test cell with dry air insulator gas at normal atmospheric pressure.

Figure 4.1 shows the data obtained from these tests. The useful frequency range was limited at 1 kHz on the low end by the maximum available voltage and at 20 kHz on the high end by the power amplifier distortion. The breakdown voltage of PZT ceramic decreases with increasing frequency at a rate of approximately 6 dB per decade of frequency. The data points associated with high-level corona discharges and parasitic current peaks were determined using the oscilloscope, but lower level corona was not as easily observed. Corona discharges with a minimum level estimated at 500-1000 pC could be seen on the oscilloscope. The corona inception voltage (CIV) curve shown in Fig. 4.1 was estimated from similar results obtained using a 60 Hz corona detector. The flashover event corresponding to the data for the top curve of Fig. 4.1 was destructive to the PZT ceramic specimen under test.

The implication of the results shown in Fig. 4.1 is that the common assumption of breakdown voltage remaining constant with increasing frequency is not valid. This factor must be considered when writing transducer electrical specifications and test procedures. A transducer that passes a 4.5 kV, 60 Hz high-voltage test could easily fail when operated at a few kHz frequency and 3 kV voltage. This means that expanded capability to test transducers with high voltage at the frequency of operation is needed. Also implied by these tests is that a dc high-voltage test for electrical insulation integrity may be almost useless.

Figure 4.2 shows estimated voltage stress curves based on the parasitic current curve of Fig. 4.1. The purpose of Fig. 4.2 is to emphasize the complexity of using the voltage stress parameter in electrical specifications. The curves are presented as a function of frequency for three common thicknesses of PZT ceramic (0.635, 0.953, and 1.27 cm). The variation of this function with ceramic thickness was determined from previous measurements [2] and is approximately proportional to the 0.5 power.

Voltage stress is obtained by dividing the applied voltage by thickness. The points on the curves of Fig. 4.2 may be computed using the empirical formula.

$$\text{Voltage stress} = 3.76\ d^{.5}\ f^{-.3}/d \qquad (3)$$

where voltage stress is in kV per cm, d is ceramic thickness in cm and f is operating frequency in kHz. It is observed from the curves that optimum voltage stress cannot be specified without knowing the ceramic thickness and operating frequency in advance.

4.4. PLANS

- Complete the report described in paragraph 4.3.2.
- Study screening procedures to identify useful coating materials for transducer corona reduction
- Select and purchase materials to be used in the tests; purchase or build necessary test fixtures

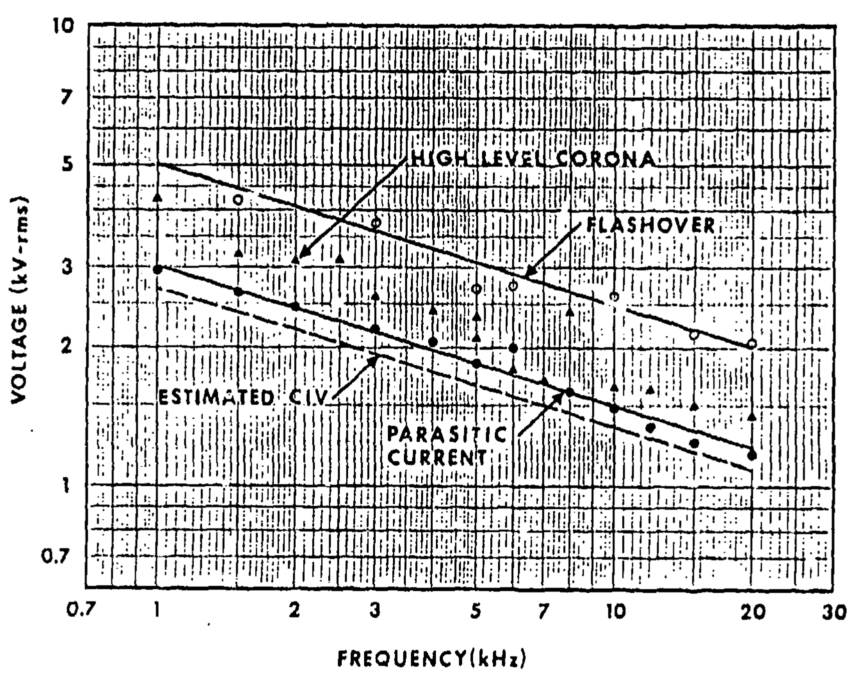

Fig. 4.1 - Frequency variation of electrical discharges on 0.635-cm thickness PZT ceramic in air.

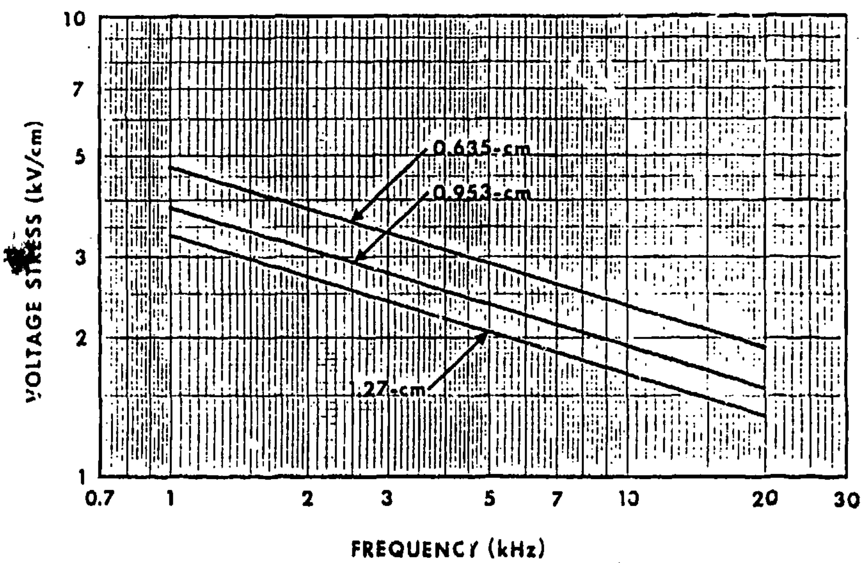

Fig. 4.2 - Calculated variation of voltage stress for different PZT ceramic thicknesses and frequencies.

5. TASK C-1 - HANDBOOK FOR CONNECTOR AND CABLE HARNESS DESIGN

R.F. Haworth - Electric Boat Division
General Dynamics Corporation
G.D. Hugus - NRL-USRD

5.1. BACKGROUND

The selection of pressure-proof connectors and cable harnesses for hydrophones and transducers is a critical part of Navy shipboard sonar system design. Yet, the design of these components for use in this environment is not covered in any one reference publication. Information on this subject is contained in a multitude of military and industry specifications, standards, and publications. The result is that engineers and designers often duplicate work and may overlook relevant information that they need.

5.2. OBJECTIVE

The objective of this task is the preparation of a design handbook covering the technology of pressure-proof underwater connectors and cable harnesses for hydrophones and transducers. The emphasis will be on the application of these components for use in naval surface ships and submarines.

5.3. PROGRESS

Work to fulfill this objective began on 31 January 1980 under contract N61339-80-C-0021 by the Electric Boat Division of the General Dynamics Corporation. The drafts of the following sections of the handbook have been completed and the table of contents are listed for each. Sections 1 through 7, 12, and Appendices A and B have been completed and were discussed in the last quarterly report [3].

- SECTION 8 - OUTBOARD CABLE DESIGN
    - General
    - Outboard Cable Design Parameters
    - Submarine Outboard Cable Design
        - Conductors
        - Conductor Stranding
        - Conductor Insulation
        - Conductor Lay Length
        - Shields
        - Shield Insulation
        - Cable Fillers
        - Cable Core Binder
        - Cable Jacket
        - Cable Types and Sizes
        - Cable Specifications

DSV Outboard Cable Design

- SECTION 14 - QUALITY CONTROL CONSIDERATIONS
- SECTION 15 - TYPICAL FAILURE MODE AND EFFECTS ANALYSIS FOR CONNECTORS AND CABLE HARNESSES
- APPENDIX C - LISTING OF SUPPLIERS AND PERSONNEL INVOLVED IN PRESSURE-PROOF CABLE, CABLE HARNESS, CONNECTOR, AND HULL-PENETRATOR DESIGN AND USE

5.4. PLANS

The first quarter of FY81 will be devoted to reviewing the handbook which is currently scheduled for publication during the second quarter of FY81.

6. TASK C-2 - STANDARD FOR O-RING INSTALLATION

C.J. Sandwith - APL, University of Washington
G.D. Hugus - NRL-USRD

6.1. BACKGROUND

The reliability of sonar transducer arrays can be significantly improved by the adoption of standard procedures for the installation and assembly of O-ring seals. The problem is that no such standard procedure exists. Presently, the installation procedures are determined by the installer and the materials available at the time of installation.

The results of analyzing failures of O-ring seals in connectors used in underwater applications over decades show that roughly eight out of thirteen O-ring failures have resulted from improper installation and assembly or improper quality control and inspection procedures at the time of assembly. Stated another way, the results showed that even though O-ring seal design may be perfected by the proper O-ring type selection (piston, face, or crush) by the maximum crush section thickness, by selecting the proper O-ring size and material, and by using two O-rings in series (double O-rings) a substantial number of the O-ring failures will occur due to improper installation and inspection procedures.

6.2. OBJECTIVES

The objective is to compose, critique (by authorities), edit and present in final form a standard procedure for the installation of O-ring seals in electrical connectors and undersea static applications. The standard will be composed in the form of similar military standards in handbook form. Once it is approved by NRL and NAVSEA authorities, it will be submitted for approval as a military standard.

6.3. PROGRESS

Work to fulfill this objective is being performed under contract N00024-78-C-6018 by the Applied Physics Laboratory of the University of Washington. The approach to developing this procedure is to use all known proven techniques and procedures of users (military and commercial) and suppliers to develop a unified best procedure. The approach is to collect from the literature, users, and suppliers, all of the data and recommendations concerning each phase of the O-ring seal production.

The rough draft of the standard procedure section on O-ring installation is complete and has been described in the previous quarterly report. This section describes the proper method of O-ring installation in new or used connectors of systems for marine and other static pressure applications.

A rough draft of five additional sections of the handbook has been completed; the sections are summarized as follows:

- SECTION 8 - PACKAGING

  The packaging methods prescribed in this section are intended to accomplish the following:

  - Assure positive identification of each O-ring (and accompanying backup O-rings if required) by part number, batch, and cure date until it is installed in the connector or component.

  - Assure positive identification by singly packaging O-ring and marking each package. Thus the need and expense of marking or color-coding individual O-rings is reduced.

  - Provide protection of each O-ring from contamination, oxidation, and radiation damage until installation.

- SECTION 9 - STORAGE AND AGING

  The intent of this section is to show how to increase the storage life as well as the service life of O-rings. This can be accomplished by knowing when the life has been decreased by adverse storage or use and by knowing the estimated life of O-rings under expected (normal) storage conditions. Knowledge of both adverse and beneficial conditions allows proper action of storing and discarding O-rings. Storage life as used here includes the time that O-rings are in the possession of the supplier, shipper, stockroom, installer, and installed in the unit but in storage before use.

- SECTION 11 - TOOLS

  The purpose of this section is to describe the acceptable tools and their proper use for removal, installation, and checking of O-rings without damaging the sealing surfaces, the O-rings, or the tools.

- SECTION 13 - RELIABILITY

  This section explains how and why the design, materials, installation, and use of O-ring seals affect the reliability of connector seals. The general concepts of reliability and its relation to probability are discussed.

- SECTION 14 - LUBRICANTS

  A list of satisfactory lubricants for static O-ring seals in marine environments is given. The lubricants are briefly discussed to indicate differences and features. The best or preferred lubricants for specific applications are recommended. Applicable standards and specifications are mentioned.

6.4. PLANS

The first draft of the entire standard procedure will be completed during the first quarter of FY81, submitted to the three chosen reviewers, and final publication will be initiated.

7. TASK C-3 - CABLES AND CONNECTORS

D.E. Glowe - Texas Research Institute, Inc.
G.D. Hugus - NRL-USRD

7.1. BACKGROUND

The use of cables and connectors is an area of concern for long-term sonar reliability because of a history of failures. Deficiencies can be generally categorized in the four areas of: design of cables and terminations; specification and testing; handling; and repair and maintenance. Specific problems have been identified in a recent failure modes and effects analysis of cables and connectors prepared for NAVSEA by General Dynamics/Electric Boat Division. They concluded that, of all the problem areas, the loss of bond of the molded boot to the connector shell or to the cable sheath is the most probable cause of failure. Cable jacket puncture in handling, at installation, or in service is considered to be the second most probable cause of failure.

7.2. OBJECTIVES

The general objective of the task is to provide improved reliability in the cables, connectors, and related hardware for the outboard elements of sonar transducer systems.

Specific objectives for the FY80 task area are to complete the following:

- Investigate the strength of shielded and unshielded cable to determine reliability and failure modes.
- Investigate the use of cable/connector boot clamps to determine reliability and failure modes.

7.3. PROGRESS

7.3.1. Work under contract N00173-79-C-0129 by Texas Research Institute, Inc. (TRI) will be concluded at the end of this fiscal year. The final report on the investigation of the strength of shielded and unshielded cable is complete. A summary of this investigation was given in the preceding quarterly report [3].

7.3.2. Work on the investigation of the use of cable/connector boot clamps to determine reliability and failure modes is continuing. Progress to date is summarized as follows.

The objective of this investigation was to determine the effect on life, performance and reliability of applying mechanical clamps to the elastomer boot of Portsmouth Connectors (MIL-C-24231). Procedures used by Navy

facilities for manufacturing connectors were reviewed, and two elastomer molding systems representing accepted materials were identified for testing. These were polyurethane PRC-1547, manufactured by Products Research and Chemical Company, and neoprene compound 319,757-1, manufactured by Joy Manufacturing Company. Commercially available clamps were reviewed for application to the molded boot over the connector backshell and at the boot/cable interface. Three clamp styles were selected for evaluation: Oetiker single ear, Band-IT preform, and Band-IT SCRU-LOCT.

To measure the effect of clamps applied to the connector, a test connector was designed and instrumented to detect leakage during test. The leakage paths measured were between the molded boot and cable jacket, and between molded boot and metal connector backshell.

A factorial matrix of 32 test connectors was assembled. The purpose of the factorial matrix was to identify the band/elastomer combination most effective so that a statistical comparison could be made between the identified combination and a control connector. The test sequence based on the mission profile was used for the matrix evaluation. The factorial matrix was measured for eleven test cycles. Analysis of the data indicated that connectors made with neoprene outlasted those of polyurethane and that both Band-IT clamp types outperformed the Oetiker clamp.

An additional 64 connectors were made to confirm the factorial data. Of these, 32 were polyurethane control connectors without clamps and 32 were neoprene connectors with Band-IT preformed clamps. All of the neoprene connectors were fitted with clamps over the metal bond area. Sixteen of these were clamped at the boot/jacket interface and sixteen were not clamped over the cable.

Based on the limits of the mission profile for connectors, an Accelerated Life Test (ALT) sequence was designed to evaluate the 64 connectors. This plan is shown in Table 7.1. Resistance measurements to indicate leakage at the backshell bond and at the cable bond were made after each pressure sequence.

After nineteen weeks of the ALT sequence, one neoprene connector was removed because of manufacturing defects and 6 polyurethane control connectors were removed for the reasons noted in Table 7.2.

7.4. PLANS

The final report on the shielded and unshielded cable strength investigation will be published during the first quarter of FY81. The ALT sequence will continue until enough failure data are obtained to confirm life and reliability of the connector configurations. This work will continue in FY81.

CYCLE	TIME (HRS)	TEMP (°C)	CONDITIONS
1	64	70	seawater soak
2	1	-78	dry cold
3	7	70	dry heat
4	16	70	seawater soak
5A*	8	25	fresh water and pressure cycle
5B*		70	seawater soak
6	16	70	seawater soak
7A*	8	70	seawater soak
7B*		25	fresh water and pressure cycle
8	40	70	seawater soak
9	1	-78	dry cold
10	7	70	dry heat
TOTAL -	168		

REPEAT CYCLE

* Order reversed for one-half of the connectors

Table 7.1 - ALT Test Plan

CONNECTOR NUMBER	TYPE	CYCLE FAILED	ANALYSIS
2	Neoprene	1	Manufacturing defect
29	Polyurethane	1	Manufacturing defect
14	Polyurethane	4	Bond failure backshell
24	Polyurethane	8	Cracked during cold cycle due to handling
13	Polyurethane	9	Bond/molding failure at cable
32	Polyurethane	11	Bond failure back-shell, molding cracked at cable
26	Polyurethane	18	Bond failure cable, molding cracked at cable

Table 7.2 - ALT Connector Failure Analysis

8. TASK D-1 - ALTERNATIVE MATERIALS: PLASTICS

K. Niemiller - NWSC

8.1. BACKGROUND

Corrosion, cost, and acoustic characteristics are parameters that must be considered when selecting a material for the design of a sonar transducer. In the past decade, plastics have decreased in cost and increased in strength to the point that they are in strong competition with metals for specific applications. Plastics could be used as a design material for sonar transducers in order to lower costs and lengthen service life if they can withstand the ocean environment. An additional advantage is that plastics generally are electrically nonconductive and acoustically transparent.

Specifically, the injection molded thermoplastics are the best materials for consideration as an alternative assembly material since they can be molded to close dimensional tolerances and in many configurations. Metals and electronic connectors can be molded directly into the plastics thus reducing the number of separable parts and insuring in-service reliability.

Naval facilities equipped with the proper molding equipment can fabricate replacement parts for sonar transducers when parts are not in stock or readily available. This would be extremely helpful when emergency repair is necessary and the time for normal procurement procedures is not available. In the event that a shortage of material should occur, thermoplastics can be easily recycled.

Presently there is no general long-term ocean immersion datum available for thermoplastics. It would take many years of testing and analysis to determine the long-term life expectancy, but there is an immediate need for information. The only approach for determining this information in a reduced time period is to perform Accelerated Life Testing (ALT), but this must be used with caution. When this method is used, it is always recommended that a comparison be made to parts which have been exposed to the actual environment in question.

8.2. OBJECTIVE

The objective of this task is to evaluate the ability of plastics to withstand an ocean environment and to determine the reliability of the ALT method for use in determining long-term material life expectancy.

8.3. PROGRESS

The approach to the objective has been to perform a two-year equivalent ALT on eight types of glass-filled thermoplastics. Parallel to

this, the same materials will be exposed to an ocean environment for two years. Water absorption, volume change, tensile and shear strength, and sound speed will be measured on all samples. A comparison of the results of the ALT and the ocean test will allow a prediction of the life expectancy of these plastics in sonar applications.

The plastic material for molding test specimens was received (approximately two months late) and molding of the test specimens completed. Testing of samples to establish baseline data commenced in August 1980. The tensile strength measurements for samples of seven materials were 47 to 67% of the listed values for the specific material tested. Tensile strengths measured and listed values for the seven materials are:

MATERIAL	TENSILE STRENGTH MEASURED (psi)	LISTED VALUE (psi)
Polycarbonate	11,517	21,000
Polysulfone	11,667	20,000
Polyphenylene Sulfide	15,320	23,000
Nylon 6/10	14,070	26,000
High-Strength Nylon (ZYTEL)	11,270	24,000
Amorphous Nylon	14,139	25,000
PBT Polyester	13,159	22,000

(The eighth material (NORYL) specimens were supplied by the manufacturer and were satisfactory)

The test specimens were visually examined, actual molding parameters and manufacturer's recommended mold parameters were reviewed. It was concluded that the molding equipment used was not capable of providing the necessary molding conditions to produce samples with strength properties acceptable for this program. Mold temperature was 180°F vice 220-250°F recommended by the supplier. Injection pressures above 15,000 psi (minimum recommended by supplier) were obtained, but only by reducing the gate opening which reduced the mass flow rate into the mold cavity. The lower mold temperature and reduced mass flow rate caused too-rapid material cooling and inadequate bonding of the plastic to the glass fibers. This resulted in the low tensile strength values.

The ocean test specimens were placed in an ocean environment on 30 July 1980 at the Naval Research Laboratory's Corrosion Testing Laboratory in Key West, FL. Dr. Bogar, of that laboratory, made sample withdrawals after one and three weeks of exposure and returned the specimens to the Naval Weapons Support Center in Crane, IN, for tests.

(The withdrawals were made prior to the determination that the samples were unsatisfactory for the program.) Only the NORYL samples were tested as the other samples were not satisfactory for the program.

Sound speed measurements were made on the NORYL samples using equipment and procedures provided by NRL-USRD.

Additional test specimens have been ordered from the material supplier (LNP, Liquid Nitrogen Products) to replace the unsatisfactory samples. The estimated delivery date for the test specimens is 13 October 1980.

Recently, recommendations were made for evaluating additional parameters of creep and degradation when fatigued or stressed. These are important considerations, but time and funds make it impossible to perform this analysis in this project time frame (FY80). These topics will be investigated during FY81.

One property evaluation that will be performed in addition to the existing procedure is the effect of seawater on machined plastics. This will be accomplished by milling the surfaces of molded test specimens of selected materials. The parts will be evaluated according to the aforementioned proceudre, but tested at lesser intervals. This will provide some indication whether or not machining does drastically affect strength and the resistance to moisture absorption.

8.4. PLANS

- Receive test specimens from supplier - mark, weigh, and measure all specimens (Oct 1980)
- Test plastics for baseline data
- Install parts at ocean test site (5 Nov 80)
- Begin ALT in laboratory (Nov 80)
- Evaluate materials in detail to determine trends in degradation
- Prepare procedure for evaluating creep, stress degradation, and machined plastics degradation

9. TASK E-1 - STANDARDIZED TEST PROCEDURE

J. Wong and D. Huckle - NOSC

9.1. BACKGROUND

It is at present not possible to subject a transducer specimen to a series of environmental stresses over a short time period and prove, if it passes certain operating parameter tests, that the specimen is a reliable transducer with a certain minimum expected life in fleet use. Of course, if we could simply use a set of transducers for the desired fleet life, we could check the failure rates against acceptable replacement or repair rates. But the approach here is to accelerate the environmental stress actions and thereby subject the transducer specimen to seven years of life cycle stresses in a few weeks or months.

9.2. OBJECTIVES

The objective of this task is to develop a set of standardized procedures based on environmental stress requirements to accelerate the aging of transducers.

9.3. PROGRESS

9.3.1. Continuation of First Year Equivalent Composite Unit Accelerated Life Testing (CUALT) on TR-316 Projectors

The first-year equivalent of CUALT on the Ametek/Straza TR-316 (first article) projectors (serials A1 and A3) was started in the last quarter. CUALT on the TR-316 projectors A1 and A3 through stress exposures 6, 2, 3, 4, 5 and the first 68 hours of stress exposure 1 (see Table 9.1) was reported in the STRIP FY80 Third Quarter Progress report. It was during this first 68 hours that the up-beam (wide-beam) section rubber window of projector A1 ruptured. CUALT on A1 was temporarily delayed. Stress exposure 1, 75°C dry heat and ultraviolet (UV) irradiation was the last exposure to complete one-year equivalent of simulated storage and service stresses for projector A3. The 75°C heat, however, exceeded the non-operating temperature range of -54°C to 71°C stated in paragraph 3.2.5.1 of the Critical Item Procurement Specification (CIPS) dated 10 June 1977. After the first 68 hours of the dry heat exposure the oven air temperature was lowered from 75°C to 71°C as indicated in exposures 1 and 2 of Table 9.2. Table 9.2 lists the revised stress exposures recommended per mission profile (per year) for the TR-316 or the DT-605 [4] and will be followed in future CUALT.

Exposures 1 and 2 in Table 9.2 represent both duty-cycle increase and accelerated aging. The 411 hours of 71°C dry heat and UV is a duty-cycle increase to simulate the extreme in service per mission profile for 1.5 hour per day of noonday sun for a dockside period of nine months (274 days).

	EXPOSURE	TIME	PURPOSE	TIME COMPRESSION	EQUIVALENT SERVICE
1.	Dry Heat 75°C UV Exposure	475 Hrs	Accelerate rubber degradation, reaction between fill-fluid and components, mechanical stress on boot due to expansion, degradation of rubber, simulate dockside storage. TEST: BEAM PATTERN, TVR, OIL PRESSURE, RUBBER CHANGES, MEGGER	Accelerated Aging Duty Cycle Increase	16,300 hrs at 21°C (E = 13,000) 1-2 hrs/day of sunlight for 9 months
2.	Fresh Water 60°C*	40 Hrs	Water permeation, simulate wet operation. TEST: MEGGER	Accelerated Aging	575 hrs at 20°C (E = 13,000) 18,750 hrs at 20°C (E = 30,000)
3.	Pressure Cycling	250 Cycles	Mechanical stress, water intrusion, water permeation, simulate diving conditions.	Duty Cycle Increase	1 year diving
	Pressure Dwell, 600 psi	2X16 Hrs Ea	Mechanical stress, water intrustion, water permeation, simulate diving conditions TEST: MEGGER, ACOUSTIC PROBE	Duty Cycle Increase	32 hrs at pressure
4.	Thermal Shock -54° to 0°C	3 Cycles	Mechanical stress due to contraction elastomer and adhesive integrity, water intrusion, simulate arctic conditions	Duty Cycle Increase	1 arctic mission
5.	Repeat Pressure Cycling & Dwells	←	SAME AS EXPOSURE NO. 3 TEST: BEAM PATTERNS, TVR, IMPEDANCE		→
6.	High-Power Drive*	168 Hrs	Simulate continuous operation	Duty Cycle Increase Stress Increase	1 arctic mission

* UV, fresh water 60°C and high-power drive exposures are eliminated for the DT-605 hydrophone.

Table 9.1 - Composite Unit Accelerated Life Test (CUALT) Simulating One-Year Equivalent of Stress for TR-316( ) or DT-605* (Revised Jul 1978)

	EXPOSURE	TIME	TIME COMPRESSION	EQUIVALENT SERVICE
1.	Dry Heat 71°C and UV Irradiation*	411 Hours	Duty-Cycle Increase	71°C, 1½ hr/day, 9 mos
2.	Dry Heat 71°C	244 Hours	Accelerated Aging	20°C, 22½ hr/day, 9 mos (E = 13,000)
3.	Thermal Cycling/Shock** (High Temperature) 71°C to 20°C	30 Cycles	Duty-Cycle Increase	30 dives from hot surface
4.	Fresh Water 71°C**	60 Hours	Accelerated Aging	3 mos mission at average water temperature of 15°C (E = 13,000)
5.	Thermal Cycling/Shock (Low Temperature) -54°C to 0°C	3 Cycles	Duty-Cycle Increase	One Arctic mission
6.	Pressure Cycling 60-4100 kPa**	180 Cycles	Duty-Cycle Increase	180 dives
7.	Pressure Dwell 4100 kPa**	180 Hours	Duty-Cycle Increase	Deep operation
8.	Electrical Drive*	168 Hours	Duty-Cycle Increase	One Arctic mission

* UV exposure and electrical drive are not required for the DT-605 hydrophone.
** Fresh water and thermal cycling/shock exposures can be combined as can pressure cycling and pressure dwell exposures.

Table 9.2 - Revised Composite Unit Accelerated Life Test (CUALT) per Mission Profile for TR-316 or DT-605*

The 244 hours of dry heat only exposure is an accelerated aging for the balanced of the dockside time at 22.5 hours per day at an assumed mean temperature of 20°C.

Six General Electric RS sunlamps were initially used in the oven for the UV exposure. These six sunlamps, two rows of three lamps, with lamp centers separated 0.254 m apart, were mounted on a plane with the four corner lamps forming an 0.254X0.508 m rectangle. The two TR-316 projectors were positioned approximately on the diagonal plane of the 1.22-m high, 1.22-m wide, and 0.61-m deep oven chamber with the projectors' rubber windows facing the sunlamps. The plane of the sunlamps was not parallel with the oven chamber diagonal plane in which the projectors lie. The up-beam sections of the projectors are nearest to the sunlamps at about 0.36 m and the down-beam sections are farther away at about 0.7 m. From intensity measurements on the GE RS sunlamps by Texas Research Institute, Inc., the six-sunlamp configuration is estimated to provide a maximum intensity of about 28 W/m^2 at the up-beam section to a minimum of about 7 W/m^2 at the down-beam section in the UV wavelength band of 280-400 nm. As a comparison, noonday solar ultraviolet radiations (wavelength of 300 to 380 nm) on a horizontal surface in Los Angeles during October 1967 have been measured to be about 30 W/m^2 and 25 W/m^2 for cases of clear and polluted conditions, respectively [5]. The heat from the six sunlamps was sufficient to maintain the circulated air temperature in the oven at 75°C. However, to maintain an oven air temperature of 71°C only five sunlamps were used giving the corresponding maximum and minimum UV intensities of 24 and 6 W/m^2, respectively.

During the 71°C UV exposure on projector A3 the temperatures at three locations on the up-beam section as well as on the oven air temperature were monitored. Thermistors were attached with high temperature tape on the rubber window and metal surfaces that were exposed to the sunlamps, and on the underside of the beam section that was shielded from the sunlamps. Measurements indicate that the metal surface that was shielded from the sunlamps stabilized at the same temperature as the oven air temperature of 71°C. Both the rubber window and metal surface that were exposed to the sunlamps stabilized at 82°C, an increase of 11°C above the air temperature. In contrast, the 71°C dry heat only exposure shows that the up-beam rubber window and metal surfaces remained the same as the oven air temperature of 71°C. This verifies that UV energy is being absorbed by the rubber and metal exposed to the sunlamps.

After the completion of the first-year equivalent of CUALT, acoustic checks (input impedance, vertical beam patterns, and transmit voltage response) were performed on projector A3. Although the three beam sections appeared to be within the specifications of the TR-316 CIPS, the input impedance of the up-beam section showed considerable variation when compared to the baseline values (Fig. 9.1). Figure 9.2 shows the corresponding changes in the up-beam transmit voltage response. The data shown in these

two figures were taken with the longitudinal axis of the projector horizontal such that the active faces are pointing perpendicular with the vertical. This is the common orientation used to obtain vertical beam patterns for the TR-316. As the projector's longitudinal axis orientation is changed (e.g., vertical) the up-beam impedance changes, indicating a strong suspicion that air bubbles were present to unload that beam section thereby altering the impedance. It was verified later (after 168 hours of high drive in the second-year equivalent of CUALT) that indeed an air bubble, approximately 0.05-m wide, was found in the up-beam section. This was done by using a probe to sense the radiated signal at the active rubber window surface of the beam section when the projector was driven at low level in air. The projector was horizontal with the active surfaces face up, an orientation where an air bubble could rise to a position beneath the rubber window over the radiating head of a resonator element. When this happens, the radiated signal from that element is significantly reduced. A smaller bubble, 0.03-m wide, was also detected in the longer narrow-beam section. However, the maximum change in the impedance of this longer section is only about 15%. No air bubbles were detected in any of the three beam sections of this projector (A3) prior to the first-year equivalent of CUALT. The origin of the air in the beam section is not known. One possibility is that the air was not completely driven out in the oil-filling procedure.

The second-year equivalent of CUALT on projector A3 began with the electrical high drive (exposure 8 on Table 9.2) in July. To avoid possible cavitation at the maximum 10.5 m water depth at the NOSC TRANSDEC pool, the projector was enclosed in a water-filled pressure vessel at 690 kPa (100 psi). The entire pressure vessel was submerged to a depth of 6 m. Continuous two-second linear step frequency sweeps at 123±5 V rms was used to drive the three beam sections simultaneously. Each two-second sweep consists of 50 increasing frequencies spaced linearly across the operating frequency band as described in the last progress report [3]. The maximum voltage drive specified in CIPS is 126 V rms. No problems were encountered in the three beam sections during the continuous 168 hours of high drive. Comparison of the transmit voltage responses with those taken before the high drive for the three beams shows less than 1 dB difference. Similar comparisons of the impedances indicate no obvious defects occurred during the second-year equivalent of electrical high drive. The up-beam impedance, however, did vary somewhat, but it is still within specification. This indicates that perhaps the air bubble has migrated to a different location within the beam section. If the air bubble ever moved to the active face of the beam section the transmit voltage response and beam patterns could be severely degraded.

9.3.2. DT-605 Hydrophones

The third-year equivalent of CUALT for the two Hazeltine Corporation DT-605 (first article) hydrophones, serials A1 and A5, was completed in the

latter part of June 1980. Acoustic data (input impedance, receive sensitivity, and vertical beam patterns) measured after the third-year equivalent indicates that both hydrophones are still within the specifications of the CIPS. Comparisons of the measured receive sensitivities between the baseline and each of three-years equivalent of CUALT for each stave of the two hydrophones have not shown any trend of deterioration within the operating frequency band.

A total of 667 hours of 71°C dry heat exposure (exposures 1 and 2 of Table 9.2) was completed for the two DT-605's in the initial sequences of the fourth-year equivalent CUALT. The UV irradiation was not required since the DT-605's are located inside the submarine sail. No problems with the two hydrophones have been encountered to date.

9.3.3. AN/SQS-56 Transducer

Texas Research Institute, Inc. (TRI) has published a report, TRI Technical Report No. 7968-5.1(F), July 1980, entitled "Qualification and Composite Unit Accelerated Life Test (CUALT) Recommendations for AN/SQS-56 Sonar Transducer Elements." This report contains recommended qualification and CUALT for the AN/SQS-56 transducer element, along with background material on which the qualification and CUALT exposures were based. The background information includes:

- A functional description of the element
- Mission profiles for:
    - Transportation and storage
    - Installation and maintenance
    - Service
- Analysis of potential wearout failure mechanisms with particular attention to:
    - Moisture permeation
    - Temperature
    - Fatigue of the bias rod
    - Rough handling
    - Rubber degradation

To conserve test time on the units available for composite unit testing it is recommended that a separate piece-part accelerated life test series be applied to the exterior rubber including the rubber bonds. These recommendations will be used as guidelines for a CUALT plan on the SQS-56 in FY81.

9.4. PLANS

- Continue with CUALT on the two Hazeltine Corp. DT-605 hydrophones and complete as many as possible of the seven-year equivalent CUALT.
- Continue with CUALT on the Ametek/Straza TR-316 projectors (A1 and A3) and complete as many as possible of the seven-year equivalent CUALT.
- Complete final documentation of FY80 CUALT effort.
- Start development of CUALT procedure for the new SQS-56 transducers.

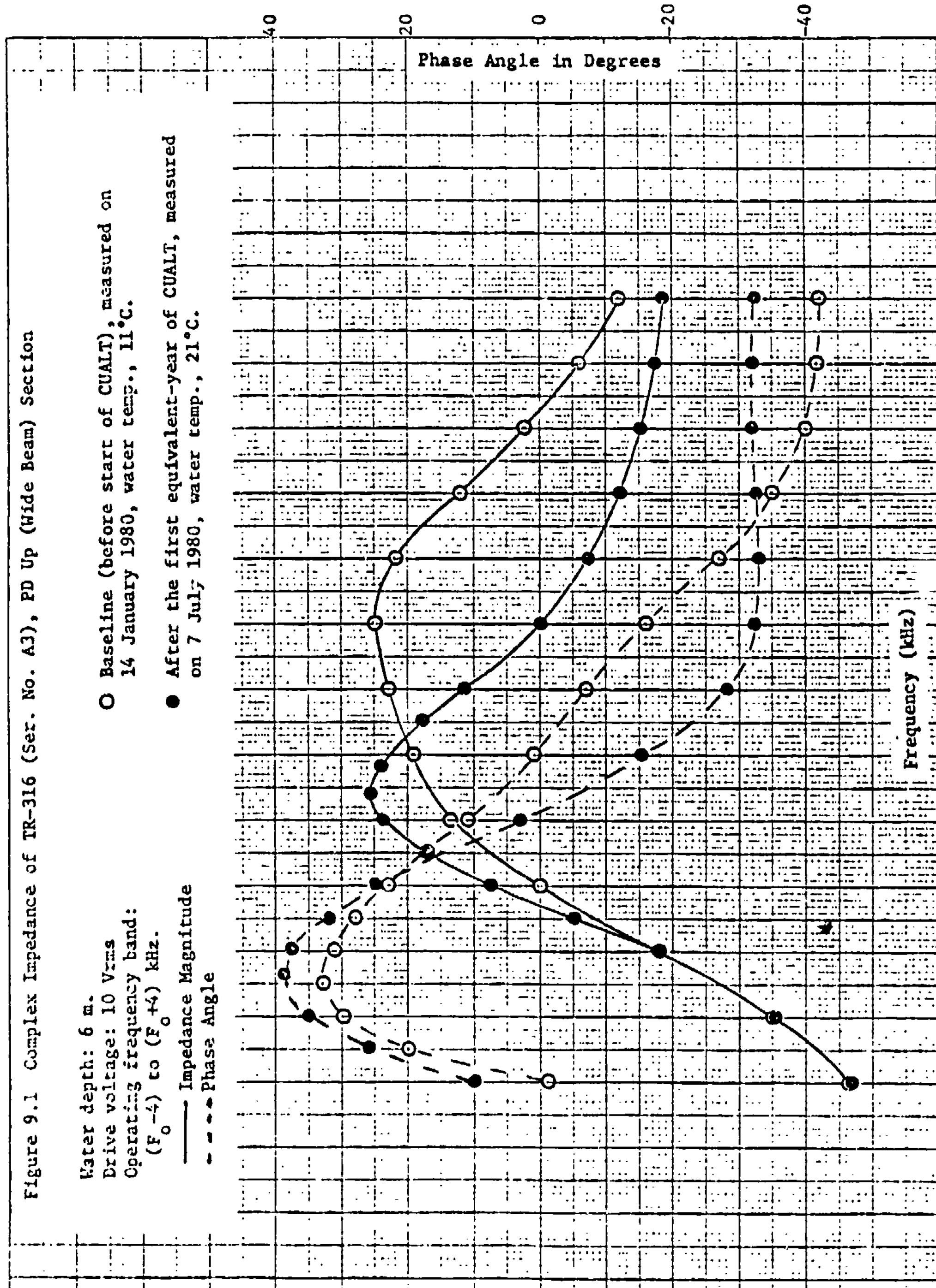

Figure 9.1 Complex Impedance of TR-316 (Ser. No. A3), PD Up (Wide Beam) Section

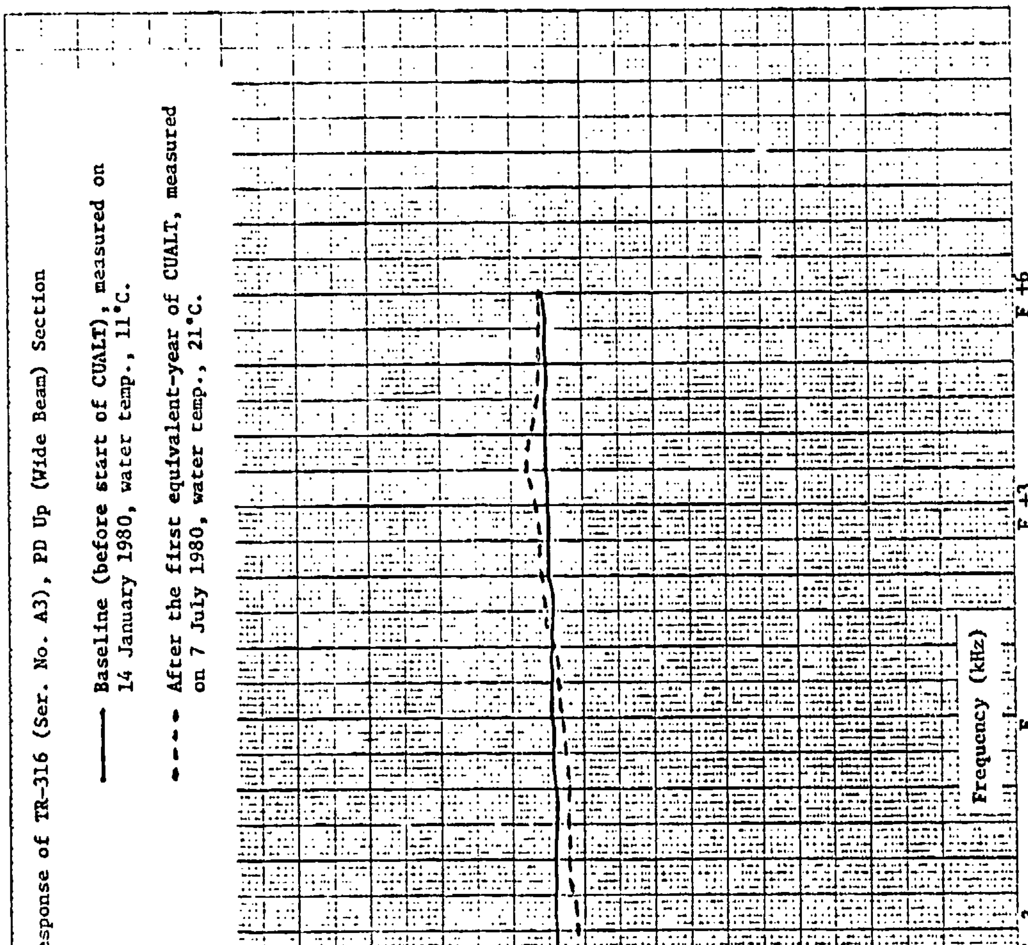

Figure 9.2 Transmit Voltage Response of TR-316 (Ser. No. A3), PD Up (Wide Beam) Section

10. TASK E-2 - ACCELERATED LIFE TEST (ALT) VERIFICATION

R. Stoddard, K. McClure, and D. Steele - NWSC

10.1. BACKGROUND

Until recently sonar transducers that were used in the fleet were fabricated and put into operation with limited life testing. Some units performed quite well throughout the expected service life while others exhibited an early high-failure rate. Costs of transducers have increased dramatically and the life requirements have been increased to fit new overhaul schedules. These and other factors have mandated verifying the reliability of units for the entire service life. In order to determine the reliability of transducers for a given time of service, it was determined that the approach of Composite Unit Accelerated Life Tests (CUALT) should be used. This method not only investigates the physical degradation of the materials used in the transducer assembly, but also the susceptibility of mechanical or electrical failures. Just as Accelerated Life Tests (ALT) for materials need to be verified by using specimens that have been exposed for the full duration to the environment being evaluated, this must also be done for CUALT.

Approximately one and one-half years ago a complete array of 48 DT-168B hydrophones was removed from the USS STONEWALL JACKSON (SSBN-634) and retained intact for post-service evaluation at the Naval Underwater Systems Center (NUSC) in New London, CT. This array of hydrophones had undergone extensive evaluation at NUSC before being installed in the SSBN-634. It was decided that these hydrophones could be used to verify the acceptability of using CUALT for hydrophones.

The DT-168B is the passive sensor for the AN/BQR-2B sonar system. This set of 48 hydrophones was fabricated by the Naval Weapons Support Center (NWSC) in Crane, IN, in 1972. Three sets of five air-backed cylindrical ceramics made of lead-zirconate-titanate (PZT-5A) wired in parallel-series are the main internal electrical components. The ceramics are protected by a steel cage that is covered by a butyl rubber acoustic window. The elements are isolated from the cage by rubber grommets. Shielded DSS-3 cable 125-ft long is used to connect each hydrophone to the system.

By fabricating ten hydrophone units identical to those in the array and performing an established CUALT on these units it will be possible to compare the degradation of these units to the information retrieved from the post-service hydrophones.

10.2. OBJECTIVE

The objective is to verify the accuracy of the CUALT method by comparing results with a known real-time life test.

10.3. PROGRESS

Ten DT-168B hydrophones were built to replicate units built in 1972 and were intended for implementation of the CUALT.

It was learned from construction of these units that fabrication of a unit that has not been fabricated for eight years has more problems than just fabrication. Small deviations from material and process requirements, thought to be unimportant in the overall function of the unit, have caused these problems. It has proven that strict adherence to materials and processes is required during a production program. The problems encountered are detailed below:

- Three of ten test hydrophones failed null balanced test but it was decided to carry them on through test for physical properties. It was determined later that there were leaking ceramics in those three hydrophones; the probable reason for the leaking was insufficient adhesive (EPON VI) used in bonding end caps on cylinders. This was the conclusion after comparison with an original (1972) ceramic removed from an old hydrophone returned from the fleet. The remedy will be to use more adhesive on another batch of ceramics. They will be allowed to cure at room temperature overnight before the adhesive is oven cured.

- Several hydrophones leaked castor oil in an area directly adjacent to the 3/8 in. bands used on each end of the hydrophone. This is the ultimate reason the decision was made to disassemble hydrophones for analysis. It was determined that, because of the use of two 3/8 in.-wide clamps rather than the 1/4 in.-wide clamps as on the originals, the clamped area was wider than the bonded area so when the boot was expanded from the pressure created in the fill process and from the increased temperature test (five days at 71°C) there was a stress concentration caused at the edge of the bands. This, along with the suspicion that the bands were installed too tightly, is the projected explanation of why the boots split allowing castor oil to leak. The remedy will be to insure that the bonded area is as wide as possible on both ends of the hydrophone, 1/4 in. bands will be used and careful attention will be given to proper installation of the bands and buckles.

- One boot split on the mold seam line - a manufacturing defect.

- It was seen after DT-168's were disassembled that nine of the ten "fifth rods" had broken loose. It is suspected that the cages were not properly sand-blasted before the bonding process and the technique used in applying the adhesive (EPON VI) may have been deficient. There also exists a possibility that two or three rods may have been too long.

- The cable molding did not adhere to the cable jacket properly. It is suspected that use of the neoprene bonding agent (googum) with the bulk neoprene used in the molding process was a mistake. "Googum" should be used if Bi-Prene tape is used in the molding process, as was done originally, but should not be used if bulk neoprene is used for molding. Bi-Prene tape has been ordered and will be used when the hydrophones are rebuilt.

The ALT plan for the DT-168's has been completed and distributed, TRI Technical Report 7973-4, by J.S. Thornton, entitled "Accelerated Aging of DT-168 Hydrophones to Simulate USS Stonewall Jackson Service." Since the purpose of the program is to establish the level of correlation between the service experience and the ALT experience of a transducer, it is necessary that the ALT plan reflects the actual service experience of the transducer set being tested. Normally, an ALT plan is generated from a universal mission profile which assumes the variety of conditions that the transducer might be expected to receive in service. In this case, it was important to use instead a mission profile that was generated from the actual service experience of the transducers. Thus, the present CUALT is specifically designed to be representative of the activity of the USS STONEWALL JACKSON rather than the total population of DT-168's in the fleet. The CUALT is not as severe as a result. For example, it is known that the array was installed within six months of manufacture by NUSC engineering personnel, which removes the need for storage exposures as well as rough handling and cable pull/flex from the pre-service profiles.

The environmental profile for the USS STONEWALL JACKSON is given in Table 10.1. Note that the thermal exposures are not severe.

Table 10.2 lists the recommended exposures and measurements for the "qualification test." The purpose of a qualification test is to insure that the unit can withstand the following:

- Transportation, storage, installation, and maintenance

- A "once through" series of exposures representative of the ALT exposures

Obviously, the DT-168 doesn't require qualifying per se, and the exposures are based on the estimates of the USS STONEWALL JACKSON experience with a pressure cycle added.

The ALT recommendation is given in Table 10.3. Note that the total time under pressure or pressure cycling is only about 200 hours compared to the 5400 hours given in the environmental profile. No time compression by increasing the pressure has been attempted. It is felt that steady pressure is not as severe as pressure cycling and that longer dwell time in laboratory exposure does not add significantly to the severity of the pressure/pressure cycling exposure.

10.4. PLANS

- Complete fabrication of the ten new hydrophones
- Test and evaluate the hydrophones
- Implement the CUALT procedure described above
- Begin ALT
- Test and evaluate the hydrophones for degradation of physical and electrical properties
- Compare the test data with that of post-service hydrophones for determination of CUALT reliability or effectiveness

No.	Exposure	Exposure Range	Occurence	Estimated Exposure	Duration
			TRANSPORTATION		
1	Pressure in Air	12 to 100 kPa	Air Transport	12 kPa flight	6 hr.
2	Temperature in Air	-50 to +32°C	Crane and New London	32°C 8 hr/day	720 hr.
3				20°C 16 hr/day 90 days	1440 hr.
4			Air Transport	-50°C one flight	6 hr.
5	Vibration	Per Mil-STD-167	Truck Transport	Per Mil-STD-167	1 series
			INSTALLATION		
6	Temperature in Air	0 to 11°C	Holy Loch	11°C 24 hr/day 30 days	720 hr.
			IN SERVICE FOR ONE YEAR		
7	Temperature in Seawater	0 to 11°C	North Atlantic/ Mediterranean Surface Waters	11°C 4 hrs/day 270 days/yr.	1080 hr.
8			Cruise Depth	4°C 20 hrs/day 270 days	5400 hrs.
9			Dockside	11°C 24 hrs/day	2160
10	Pressure in Seawater	100 to 4100 kPa	Checkout Service	4100 kPa 4 times/yr.	8 hr.
11			Service	2100 kPa 20 hrs./day 270 days/year	5400 hrs.
12	Pressure Cycling	100 to 4100 kPa	Checkout	100-4100 kPa 4 cycles/yr.	4 cycles
13			Service	100-2100 kPa 270 days/year	540 cycles
14	Vibration	Per Mil-STD-167	Service	Per Mil-STD-167	1 series

Table 10.1 - Environmental Profile - USS STONEWALL JACKSON DT-168 Array

Conduct this exposure series one time at the beginning of the test program.

Exposures

1.	Oven aging 136 hrs. at 70°C
2.	Vacuum 12 kPa (1.7 psia) 6 hrs.
3.	Cold chamber (air) 6 hrs. at -50°C
4.	Vibration per MIL-STD-167, 1 series
5.	Pressure cycle 100-4100 kPa one cycle at 1400 kPa/min.

Measurements

1. Baseline measurements per Design Specification (Code IDENT 80064 NAVSHIPS 4553328 REVA) as appropriate, should be made before the qualification exposure sequence.

2. Perform Null Balance (para 4.3.1.5) and DC Resistance (para 4.3.1.3) measurements per Design Sepcification after the qualification exposure sequence. If no change, it is not necessary to repeat the baseline measurements.

Table 10.2 - Qualification Tess

Conduct this exposure series six times after completing the qualification test.

Exposures

1.	Saltwater immersion	119 hours at 70°C
2.	Pressure/Pressure cycling	100-2100 kPa, 540 cycles, at 1400 kPa/min. 6 overnight (14-16 hr.) levels at 2100 kPa. 100-4100 kPa, 8 cycles
3.	Vibration per MIL-STD-167, a series	
4.	Repeat 1-3 for each equivalent year of service.	

Measurements

1. Perform DC Resistance per Design Specification (CODEIDENT 80064 NAVSHIPS 4553328 REVA) para 4.3.1.3 after each exposure. If no significant change, it is not necessary to repeat baseline measurements.

2. Repeat baseline measurements at the conclusion of 6 equivalent years.

Table 10.3 - Accelerated Life Test

11. TASK F-1 - ENGINEERING ANALYSIS: FAILURE MODES DUE TO WATER

D. Barrett and P.E. Cassidy - Texas Research Institute, Inc.

11.1. BACKGROUND

Previous studies have developed some of the techniques of calculating the rate of water ingress into a transducer case, but more or less severe assumptions have had to be made for these calculations to date. In addition to the assumptions about the rate of water ingress, little work has been done on the effects of the ingressed water. The various failure mechanisms that can be triggered by the presence of water are not well understood and are not quantized.

11.2. OBJECTIVES

The purpose of this task is to investigate the effects of water permeating into a transducer; specifically, to determine the effects on reliability and performance (not related to corona and arcing). The immediate objectives are to determine the effect of the rubber membrane on the permeated water and to measure the electronic changes in a transducer caused by the presence of internal moisture.

11.3. PROGRESS

The work is being done in phases which are designed to determine what happens to water once it gets into a transducer and how it affects the lifetime of the transducer. The first phase will determine the composition of the permeant - the quantity and type of dissolved solids which come through with water, whether they are from seawater or contaminants from the elastomer. The second phase will be to test the effect of water on the lifetime functions of a transducer.

The first phase of the work involves study of rubber similar to that used on transducers (WRT neoprene). Previous reports showed that a 100°C water extraction removed both organics and inorganics (magnesium and silicate salts) from the rubber. The total weight loss was subsequently determined to be 2.9%. A question was raised regarding the validity of such a process in view of the high temperature. Yet another question was the comparability of the extraction process to that of permeation, the latter supposedly being imitated by the former.

To answer the first question (that of temperature validity) the extraction experiment was repeated several times but at 70°C rather than 100°C. Of course, it was run for a much longer time to compensate for the much lower reaction rates at the lower temperature. Additionally, several different rubber formulations were run to determine if the results vary with composition. The results are given in Table 11.1.

SAMPLE	Neoprene WRT	Neoprene W (USRD Form)	Neoprene GRT (5109)	Natural (1155)
Tester	PEC (TRI)	CMT (NRL-USRD)	CMT (NRL-USRD)	CMT (NRL-USRD)
Test Time (Days)	90	53	53	53
Test Temperature	70 C	75 C	75 C	75 C
Water Appearance	Yellow with White Precipitate	Clear	Clear	Clear
Water Resistivity	11.4 ohm-cm (94,000 at start)	5300 ohm-cm (53,000 at start)	2800 ohm-cm (53,000 at start)	3800 ohm-cm (53,000 at start)
Identity of Precipitate	10.6% Si 8.4% Mg	-	-	-
Water Content	0.03% Mg	Not Analyzed	Not Analyzed	Not Analyzed

Table 11.1 - Water Extraction Test Results on Sonar Rubbers

From this data, it can be concluded that the test previously performed on Neoprene WRT at 100°C was likely a valid test of the extractability of ionic material from the rubber. An interesting additional conclusion is that the test is very sensitive to the type of rubber. The formulation of the Neoprene WRT is unknown; the Neoprene W is a ZnO-cured, lightly filled material; the Neoprene 5109 is PbO-cured and is sulfur free; the natural 1155 is a standard, soft formulation. Extrapolating these results to a transducer will require attention to the formulation of the exposed rubber.

The second question, i.e., comparison of permeability to extraction, is in the process of being answered. Two permeation cells (ASTM D1656) were anodized, one was filled with fresh water and one with salt water, and samples of the neoprene were secured in place. The faces of the neoprene were washed with deionized water (resistivity after wash equalled 100 to 115 k ohm-cm). The experiments will continue to determine if neoprene components are carried to the outer surface by water transmission and if salt from the salt water is carried through the rubber.

In the second phase, actual TR-208A transducers were used in this portion of the study to determine:

- Changes in electronic behaviors related to internal humidity

- The relationship of internal humidity to actual water content (weight)

Three TR-208A transducers were instrumented as described in the previous quarterly reports and the following work was performed:

- Initial internal humidity measured (before opening the device)

- Thorough drying of the internal atmosphere

- Electronic behavior (free-field voltage sensitivity, transmitting current response, transmitting voltage response, and directional response) was determined by NRL-USRD

- The elements were then adjusted to several internal humidity levels (23, 54, 75, and 95%) and impedance and phase-vs-frequency characteristics were measured at each humidity level

- The total water content (in grams) was determined at several humidities (in progress)

- The humidity was established at 54% and the transducers were sent again to NRL-USRD for characterization (in progress)

From the above experiments which have been completed and results analyzed to date, the following can be said:

- The initial humidities were surprisingly high (56 to 65%) considering the fact that these devices were designed to be specially water-tight

- Phase and impedance measurements showed nearly identical data for humidities of 54% and above. The 27% RH data were significantly different from all others. Therefore, some change occurs between 27 and 54% RH

- For one transducer on which the test series is complete, the most significant difference is in the Y-axis of the transmitting current response when comparing dry to 54% RH

- A TR-208A transducer with an internal RH of 57-58% was found to contain a total of 0.34-0.36 g of water. A determination of the source of this water, i.e., whether in the vapor state or absorbed on surfaces, can be made after the internal volume is measured

11.4. PLANS

- Permeation experiments will continue. Any salts which may appear on the surface of the rubber will be analyzed

- A literature search will be conducted on the composition of rubber permeants

- Electronic characterization of the elements at about 54% will be completed

- Additional comparisons of % RH to water content will be made

- An accelerated test will be performed on a TR-208A element which has a known RH

- An interim report will be prepared describing the effects of water on the operation of a transducer. This report will also include calculations on the rate of water ingress into a transducer

12. TASK F-2 - TEST AND EVALUATION: SHOCK-HARDENED PRESSURE RELEASE

C.R. Wilson - Westinghouse

12.1. BACKGROUND

A study recently completed by Westinghouse addressed the use of polyimide and glass-loaded polyester materials as a pressure release mechanism in the TR-155F transducer. Transducers using these pressure release materials in place of the "standard" Belleville springs were subjected to extraneous noise tests, acoustic tests, and explosive shock tests. While the noise and acoustic test results were encouraging, the pressure release configurations were not intended to withstand the rigors of explosive shock.

12.2. OBJECTIVES

The objectives of this task are to develop, test, and evaluate the effectiveness of polyimide and polyester-elastomer-glass as a shock-hardened pressure release material.

12.3. PROGRESS

The Westinghouse modified TR-155 transducers scheduled for explosive shock test in July 1980 were "bumped" by higher priority first article production tests. The units are now scheduled for test in November 1980. All other work has been completed and this task will be closed by Westinghouse Report OER 80-36 of 1 October 1980.

13. TASK F-3 - RELIABILITY AND LIFE PREDICTION SPECIFICATION

R.L. Smith and D. Barrett - Texas Research Institute, Inc.

13.1. BACKGROUND

The reliability and life requirements for wet end sonar equipment need to be better defined. Present handbook style reliability prediction methods do not account for redundancy. There seems to be no unified approach to carrying out a prediction of hardware life in the sonar context. Even to speak of reliability and life as independent concepts ignores their formal duality in reliability theory. Consistent improvements in reliability and life definition and prediction are needed for STRIP objectives to be met. For example, specifying MTBF does not uniquely determine the reliability in the time frame of particular interest - the first few years of service. Other factors, such as the definition of failure, and the use of redundancy in the design dominate the reliability versus time relationships. Specifying service life in years does not embrace degradation during storage nor does it uniquely define wearout reliability.

Reliability is a very strongly statistical concept based on the behavior of a group of nominally identical items. Reliability itself is a distributed quantity (i.e., best represented by a normalized distribution or probability density function). The parameters appearing in reliability models are also distributed. Inferences relating to all such quantities are based on limited sets of observations which yield only estimates of the parameters of interest. However, the methods of statistical inference allow us to make the most definitive statements possible under the circumstances.

The present approach used by the Navy for wet end sonar equipment procurements is to specify numerical reliability and life requirements in the Critical Item Procurement Specification (CIPS) and to ask the contractor to achieve these objectives through a reliability program described in attachment 2 to the contract. Unfortunately, for the reasons given above, a contractor can fulfill all the requirements as currently stated and still deliver hardware that performs less than satisfactorily.

13.2. OBJECTIVES

There are two major wet end sonar reliability objectives:

- Providing the analytical basis for improved hardware reliability
- Facilitating hardware improvemnt by developing more satisfactory procurement specifications

Intermediate subtask objectives in support of the above are:

- Learn how to analyze the superposition of random and wearout reliabilities
- Learn how to extract wearout failure mechanisms and random failure hazards from an FMEA
- Learn how to put a time scale on the wearout failure mechanisms vis-a-vis activation energies, stress amplitudes and cycling, etc
- Learn how to do a life prediction
- Improve present (random) reliability prediction methods by correct analysis of redundancy and definitions of failure
- Learn how to superimpose the results of the last two subtasks above
- Learn how to handle subjective information (Bayesian reliability)
- Figure out how the contractor can achieve the predicted overall reliability (random and life) with appropriate contractor-managed reliability achievement programs (critical parts management, piece-part testing, compatibility studies, QC inspection, design reviews, etc.).
- Learn how to tell a contractor how to do all of the above

13.3 PROGRESS

This is an analytical reliability task initiated in FY80. Work is being performed under contract N00024-79-C-6232 by Texas Research Institute, Inc. The approach for FY80 has been to complete work on intermediate objectives 1 and 5. A fairly comprehensive document fulfilling objectives 1 and 5 is near completion. This report is being generated early in the overall program because its focus is largely to expose well-developed ideas in the fields of reliability theory and probabilistic design which should properly influence the shaping of future reliability studies. The report includes the following:

1.0 INTRODUCTION AND SUMMARY

2.0 STANDARD MODELING CONCEPTS

7.0 SPECIAL RELIABILITY DIFFICULTIES FOR NAVAL SONAR EQUIPMENT

- 7.1 Heroic Time Scale
- 7.2 Gaps in the Quality and Kind of Hazard Rate Data
- 7.3 Need to Define Systems Operating Requirements
- 7.4 Undefined Process Endpoints
- 7.5 Test Method Nonuniformity
- 7.6 Need for Systematic and Uniform Data Acquisition

8.0 RECOMMENDATIONS

- 8.1 Methods Applicability
- 8.2 Recognizing the Statistical Character of the Problem
- 8.3 Data Requirements
- 8.4 Product Upgrading Strategies
- 8.5 Incentives
- 8.6 Management Needs

The report includes, in functional detail, a number of topics critical to sonar transducer technical and procurement activities. Some of this material is new and open publication avenues will be explored. Other considerations are standard textbook material. No apology need be offered in cataloging the latter in a single source for sonar personnel. Reliability studies are very complex and sophisticated and much preparation is required to appreciate basic concepts before one can hope to systematically make progress in pursuing actual hardware evaluation and improvement. The scope and topic selection of the report is structured to help Navy personnel formulate knowledgeable independent evaluations in approaching reliability and life prediction questions. Topics covered in the report include the standard reliability description of failures due to congenital defects, random hazard loading, and wearout. Weibull statistics are seen to be general enough to embrace all three situations (one at a time). The relationships of reliability and life to the underlying complexity or redundancy of a system of interest are developed. The original motivation for and current status of reliability prediction methods are discussed. Limitations are noted with particular emphasis on sonar applications. The life prediction topic is also dealt with. Life prediction really represents a microscopic approach to identifying the same serviceability attributes that reliability studies pursue macroscopically.

The two major problems that stand in the way of presenting a crisp, tidy description of the reliability/life aspects of sonar hardware are the heroic time scale of the fleet service application and the stochastic nature of the situation. These two considerations impact the cost and time scale of data acquisition as well as determining the amount of information required in support of an adequate statistical description.

Perhaps the major new topic explored under the program has been an illustrative corrosion wearout model suggesting log normally distributed times to failure. This is an appealing result since a variety of corrosion and fatigue situations are known, experimentally, to exhibit this characteristics. To date, Texas Research Institute's corrosion work has dealt with modeling the strength loss of a load bearing member such as a threaded fastener. This work is to be considered preliminary to a study of the perforation of a transducer housing due to corrosion. Housing perforation and leakage is considered to be a major wearout process associated with this structure.

An important aspect of corrosion modeling is the correct manipulation of distributed quantities. Random variable transformations and distribution syntheses have also been studied in support of estimating reliability parameters and developing confidence statements in other reliability settings. The distribution properties so fundamental to the probabilistic design field are completely overlooked in handbook prediction. The handbook approach is said to be deterministic; here the term "deterministic" does not mean correct or fully characterized, it simply means all dispersion effects are ignored.

13.4 PLANS

Plans for follow-on reliability work include a separate study addressing the expected quality of the handbook prediction method. This will be an attempt to characterize the dispersion effects normally overlooked in handbook modeling.

The corrosion modeling effort under the present contract is felt to provide the basis for a contribution to the open literature. This would be a corrosion or other wearout process study emphasizing the use of probabilistic design concepts and methods to facilitate the indirect experimental evaluation of physics-of-failure hypotheses.

Application of analytic methods to the characterization of specific failure modes of sonar transducers is recommended. This approach should be coordinated with future experimental work.

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